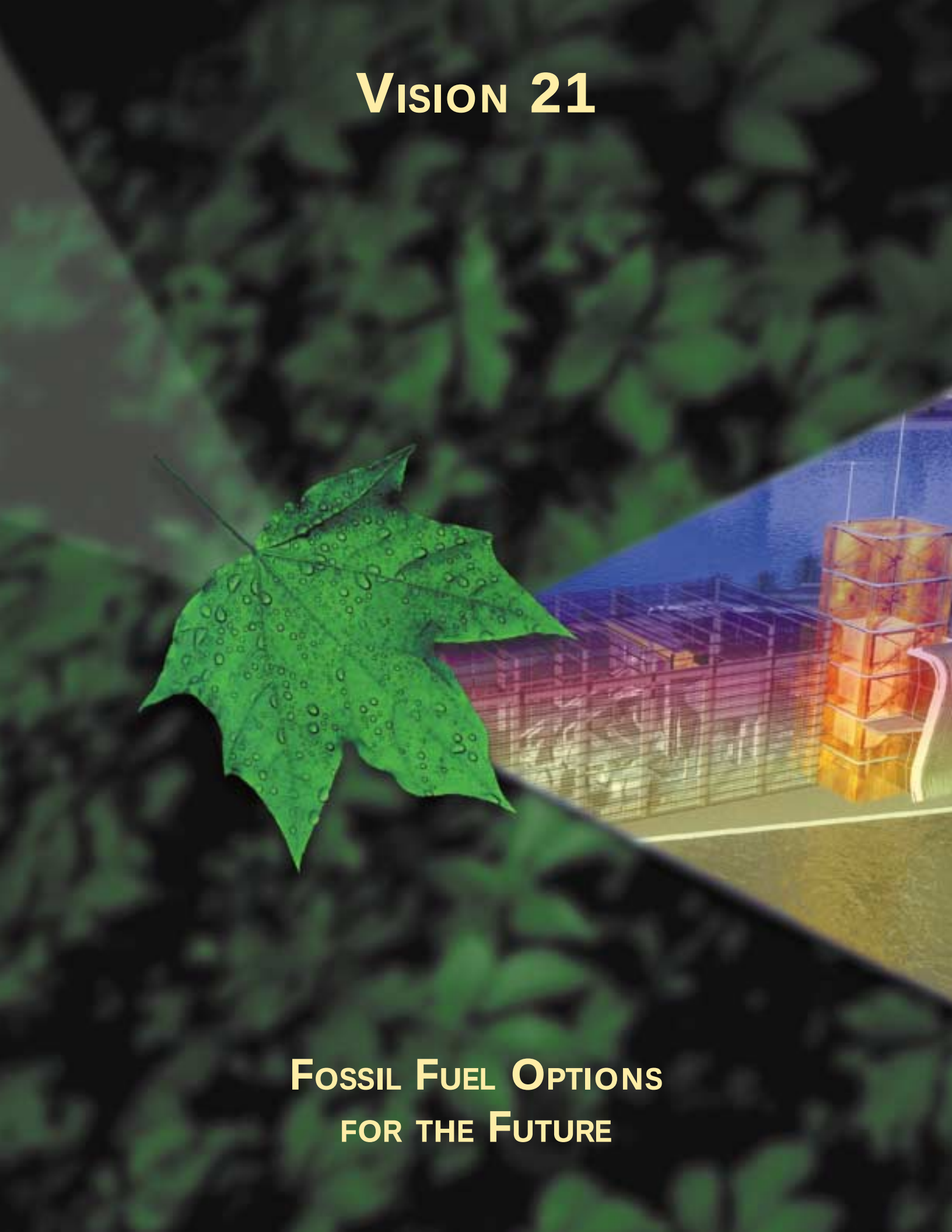
Vision 21



Fossil Fuel Options for the Future

INTRODUCTION

Program Areas

- Systems Analysis
- Enabling Technologies
- Supporting Technologies
- Systems Integration
- Vision 21 Plant Designs

The Department of Energy's (DOE) Office of Fossil Energy (FE), through the Coal & Power Systems (C&PS) program, has begun a new approach for developing 21st century energy plants that would have virtually no environmental impact.

A new approach is timely because of the unprecedented changes in the electric power industry — electric utility deregulation and restructuring, the availability of relatively low-cost natural gas, and environmental issues surrounding power production, including global climate change.

The new approach is called Vision 21. Vision 21 is a government/industry/academia cost-shared partnership to develop the technology basis for integrated energy plants that will, early in the 21st century, result in the deployment of ultra-clean plants that produce electricity and "opportunity" products, including clean transportation fuels, high-value chemicals, synthesis gas, and hydrogen.

The overall objective of the Vision 21 program is to effectively eliminate, at competitive costs, environmental concerns associated with the use of fossil fuels for producing electricity and transportation fuels. Vision 21 is based on three premises: (1) that the Nation will need to rely on fossil fuels for a major share of its energy needs well into the 21st century; (2) that it makes good sense to rely on a diverse mix of energy resources, including coal, gas, biomass and other renewables and nuclear, rather than on a limited subset of these resources; and (3) that reasearch and development (R&D) directed at resolving energy and environmental issues can find affordable ways to make energy conversion meet ever stricter environmental standards.

Today, a typical power plant uses one type of fuel, usually coal, and produces only one thing — electricity. A Vision 21 plant would be fuel-flexible, meaning it could use one or more of several different feedstocks including, coal natural gas, or petroleum coke. Any of these could be mixed with biomass. In turn, the plant could produce one or more high-value products such as electric power, clean fuels, chemicals, or hydrogen. Secondary products such as heat/steam for industrial use could also be produced. A Vision 21 plant will be capable of a variety of configurations to meet differing market needs, including both distributed and central power generation.

Vision 21 builds on the Clean Coal Technology (CCT) demonstration program experience and a portfolio of advanced technologies already being developed within the C&PS program — including integrated gasification combined-cycle, pressurized-fluidized bed combustion, advanced gas turbines, fuel cells, and fuels synthesis — and adds other critical technologies and system integration techniques.

Endorsed by the President's Committee of Advisors on Science and Technology (PCAST) in 1997 and further supported by the National Research Council in 2000, C&PS' Vision 21 program serves as a "roadmap" for future electric power and fuels R&D. Vision 21 technologies, once achieved, will offer the United States, and the world, a new method of coal-based power generation that would have significant advantages over current methods.

An artist's rendering of a Vision 21 plant.

DRIVERS

The United States currently has a diverse and relatively low-cost supply of energy, primarily based on fossil fuels, for the production of electricity, process heat, transportation fuels, and chemical feedstocks.

Relatively low-cost fossil fuel energy supplies are a critical component of the current economic prosperity and favorable trade position of the United States globally and are likely to be so for the foreseeable future. As recent PCAST studies (1997 and 1999) have shown, preserving options for using diverse energy sources is an essential element of a national energy R&D policy.

Electric Power Restructuring. One of the most significant driving forces dictating the future state of power production in the United States is electric power restructuring. As the power industry deregulates, utilities that were heretofore protected against competition and guaranteed returns on their investments are now being forced to compete for market share and profits. As a result, deregulation is changing the way the industry operates and invests in new facilities and technology. In a market-driven environment, power plant owners must be concerned about profitability and ability to finance new investments. This may cause owners to avoid technical risk and favor low capital cost and short-term alternatives, especially when such alternatives are coupled with a fuel supply contract for a period long enough for the investment to be recovered.

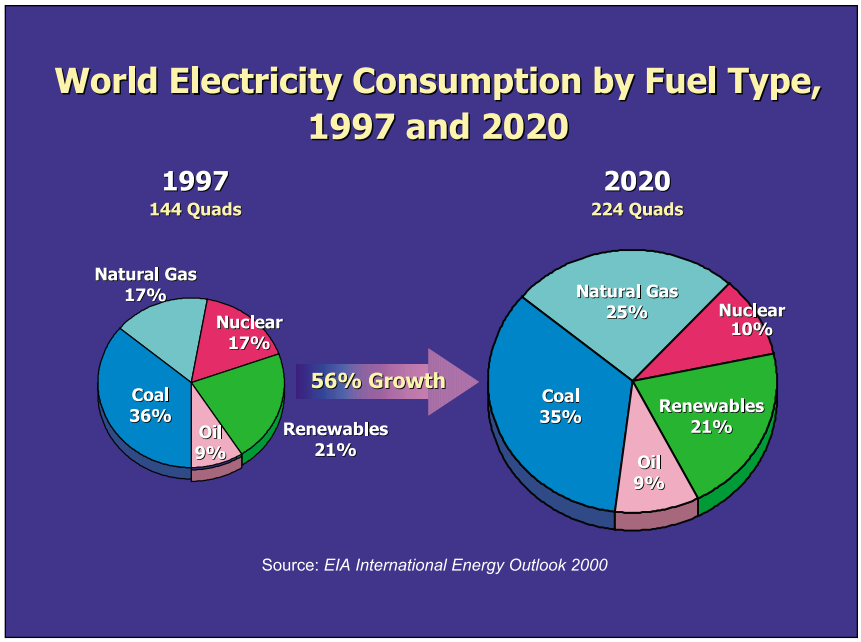
Competition Among Fuels. Today's relatively low cost of natural gas is causing power producers to favor low capital cost turbines over relatively high-cost coal-fired boilers for new capacity. The Energy Information Administration (EIA) projects that in the U.S. about 300 gigawatts (GW) of new generating capacity will be needed in the next 20 years to meet growing demand and to replace retiring units. The EIA estimates that 90 percent (270 GW) of this new capacity will be fueled by natural gas, or both natural gas and oil. Coal-based capacity will account for seven percent (21 GW) of the new capacity, and 82 percent of the 21 GW will come online between 2010 and 2020. Renewables will make up the balance of new capacity.

Competition between coal and natural gas after 2015 will be affected by many factors related to the resources themselves. Coal and natural gas are both readily available. World coal reserves are estimated to be adequate to accommodate 1996 production levels for more than 200 years. In the United States, fossil energy resources are dominated by coal (85 percent), followed by gas (10 percent) and oil (5 percent).

Natural gas production is not as widespread. In the United States, coal is exported, but natural gas is imported. By 2020, imported natural gas is projected to account for approximately 15.5 percent of total gas consumption. Six areas contain 71 percent of the proven dry natural gas reserves in the United States. Approximately half of the remaining untapped conventional natural gas resource base is on federally owned land.

In most instances, natural gas must be transported by pipeline. By contrast, coal can be transported by rail, water, or truck, and many users have access to multiple modes of transportation. A major uncertainty about the rate of increase in gas-fired power generation is the difficulty of routing natural gas pipelines to power generation sites. Difficulties in obtaining regulatory approvals for installing the new pipelines to meet future commitments may limit the rate at which baseload capacity can be partially shifted from coal to natural gas.

Global Energy Demands. Globally, energy consumption in the developing world (Asia, Africa, the Middle East, and Central and South America) is expected to more than double in the next twenty years, with the highest growth rates expected in developing Asia and Central and South America. The use of coal is projected to dominate the generation of electricity, especially in China, where in 1995, coal accounted for 88 percent of power generation. By 2020, China's demand is projected to represent 36 percent of the total worldwide demand for coal.



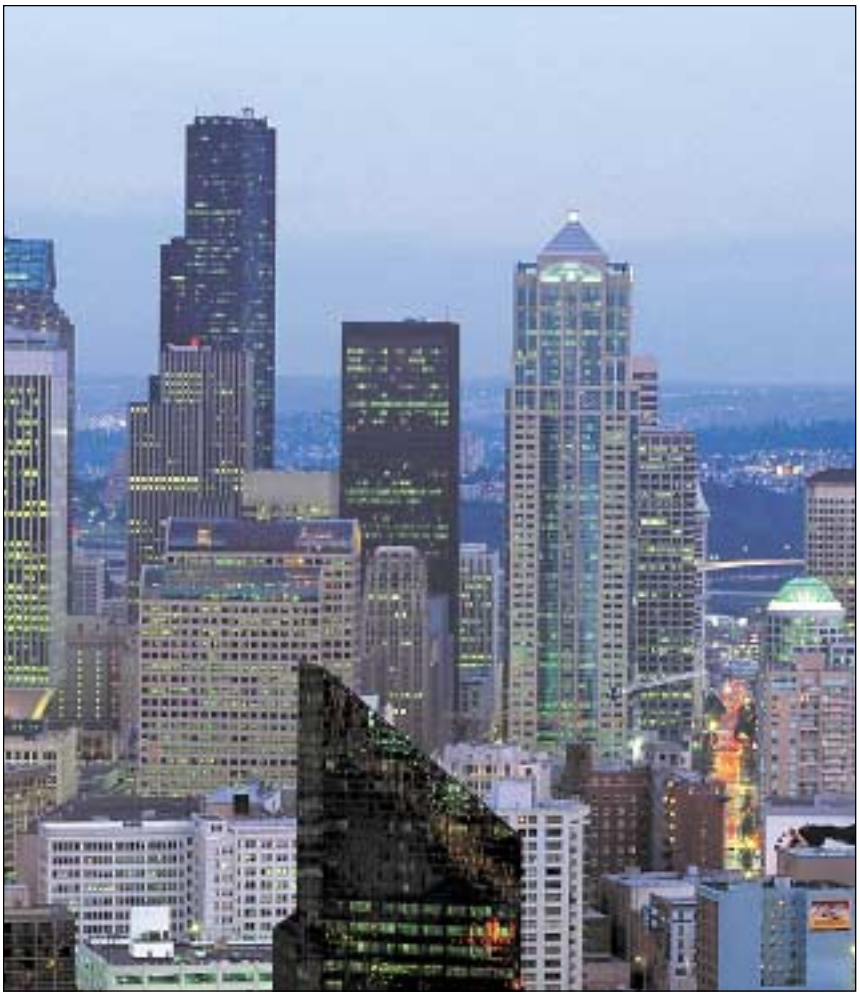
Similar growth is expected in energy consumption for transportation. The worldwide demand for transportation fuels and chemical feedstocks is expected to increase by 66 percent between 1995 and 2020; in the developing world, the demand for oil is projected to increase by 77 percent. The demand for refined petroleum products in the United States is expected to increase by 33 percent between 1998 and 2020. The greatest share of the increase is expected to be in transportation fuels, where gasoline, jet fuel, and distillate are projected to increase by 38 percent, 86 percent, and 19 percent respectively. The demand for chemical feedstocks and other nonfuel petroleum products is projected to increase by 24 percent.

Environmental Concerns. The Clean Air Act of 1970 and subsequent amendments have brought about major reductions in emissions of the acid gases, i.e. sulfur dioxide (SO_2) and nitrogen oxides (NO_x), and particulates for new coal-fired plants. Existing plants are increasingly being required to cut emissions. Moreover, renewed concern about fine particulate and its precursors (nitrogen and sulfur oxides), trace element emissions (especially mercury), and ozone (and its nitrogen oxides precursor) have created new pressures for cleaner plants. These pressures are unlikely to ease in the future; rather, each new generation of power plants will be expected to be cleaner than the last.

Perhaps the biggest change in energy production and consumption will be driven by concern over global climate change. Emissions of greenhouse gases, especially carbon dioxide (CO_2) from fossil fuel use, may need to be reduced in the future. Although a portion of this reduction may be achieved through emissions trading and credits for investing in emissions reduction projects in developing countries, it is likely that substantial reductions in carbon emissions will be necessary. Increasing the efficiency of power generation is a step in the right direction, but a technological solution that would provide sufficient reductions in carbon emissions has yet to be identified.

Conclusion. The implications of these drivers for the future economic competitiveness and prosperity of the United States cannot be underestimated. The Nation's economic future depends on a supply of affordable electricity to run factories and heat and light offices and homes, and on clean fuels for transportation. Predictions have been made about the devastating effects that limits on carbon emissions will have on the economy. However, predictions often underestimate the impacts of technological innovation. Indeed technology innovation is the best, and perhaps the only way, to address the coming challenges to the Nation's electric power and fuel supply infrastructure.

The bottom line is that the United States will need to rely on fossil fuels for the major share of its electricity and transportation fuels well into the 21st century. The Nation cannot endanger its economic future by depending on any single fossil energy source. Although the current situation favors natural gas, for the long term the wisest policy is to depend on a balanced mixture of energy sources, including gas, coal, oil, and renewables. Without new and radically better technology, the costs of energy will increase substantially and the predictions of "devastation" may turn out to be correct. On the other hand, by taking the lead on developing the needed technology, the Nation will not only meet the energy and environmental challenges it faces, but also make the economy stronger.



ACTIVITIES

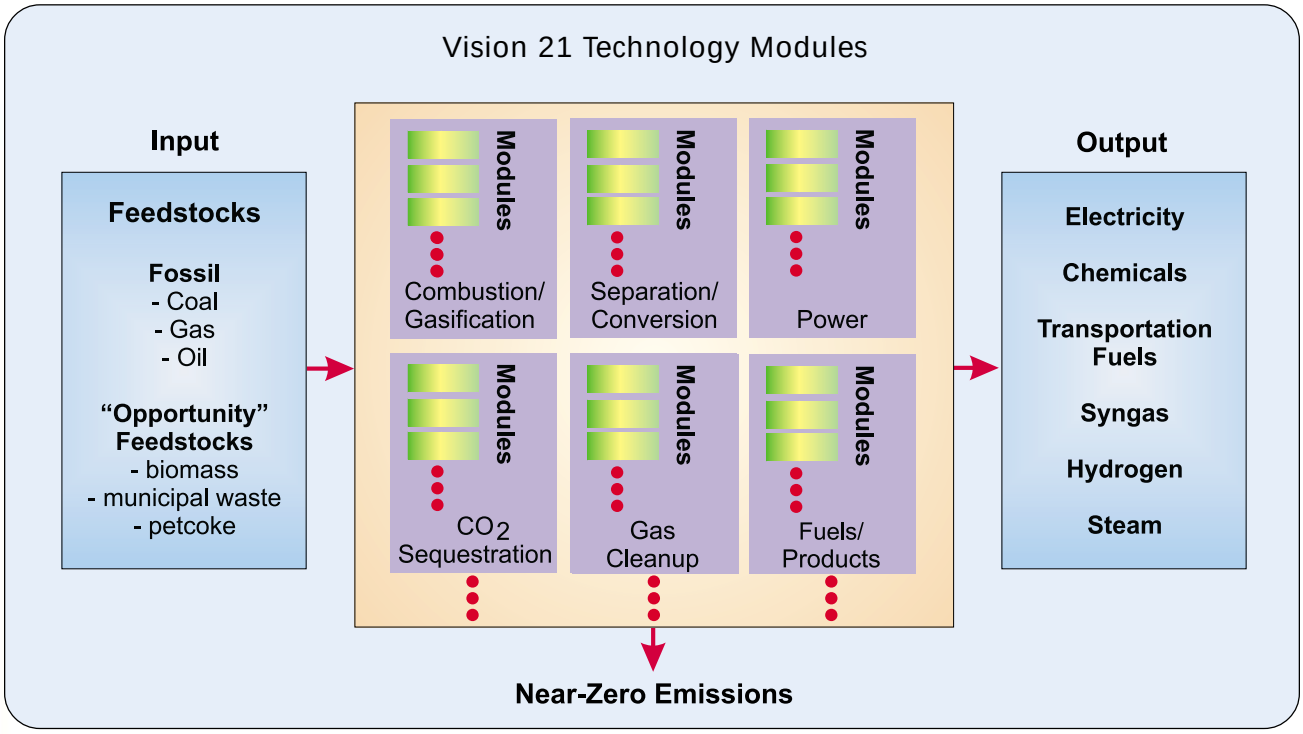
The focus of the Vision 21 program will be on flexible components and subsystems to enable modular designs for plants that can use multiple feedstocks or produce multiple products in the 2010–2015 time frame.

To establish a blueprint, FE plans to focus Vision 21 on several elements that will be common to all of the facilities under consideration:

- **Systems analysis** will be used to develop various system configurations that satisfy the program objectives, define the performance targets for individual subsystems, and identify supporting technology needs.
- **Enabling technologies**, such as advanced, low-cost hydrogen and oxygen separation and advanced gas cleaning, form the building blocks of Vision 21 plants.
- **Supporting technologies**, such as higher-strength, more durable materials, improved catalysts, environmental control technologies, sensors and controls, and virtual demonstrations, are cross-cutting technologies that are necessary for multiple subsystems and components and are important for other applications.
- **Systems integration** in a Vision 21 plant configuration will use "smart" systems integration techniques to combine high-performance subsystems into very clean and efficient low-cost plants.
- **Plant designs** that would serve as the basis for a new fleet of commercial-scale Vision 21 plants.

Modeling, analysis, and experimental work of Vision 21 technologies will range from laboratory-, bench- and pilot-scale, up to and including scales needed to obtain data for demonstrating feasibility for prototype and commercial-scale plants. However, construction of Vision 21 prototype and commercial-scale plants is not part of the Vision 21 program. These activities, the exact timing of which will depend on prevailing economic conditions and market forces, will be left to private industry. The role of the C&PS program will be to facilitate the transfer of the Vision 21 database to industry.

A more detailed discussion of the program activities and milestones for each program area within Vision 21 can be found in the Vision 21 Program Plan located on the Internet at http://www.fe.doe.gov/coal_power/vision21/v21plan.pdf.



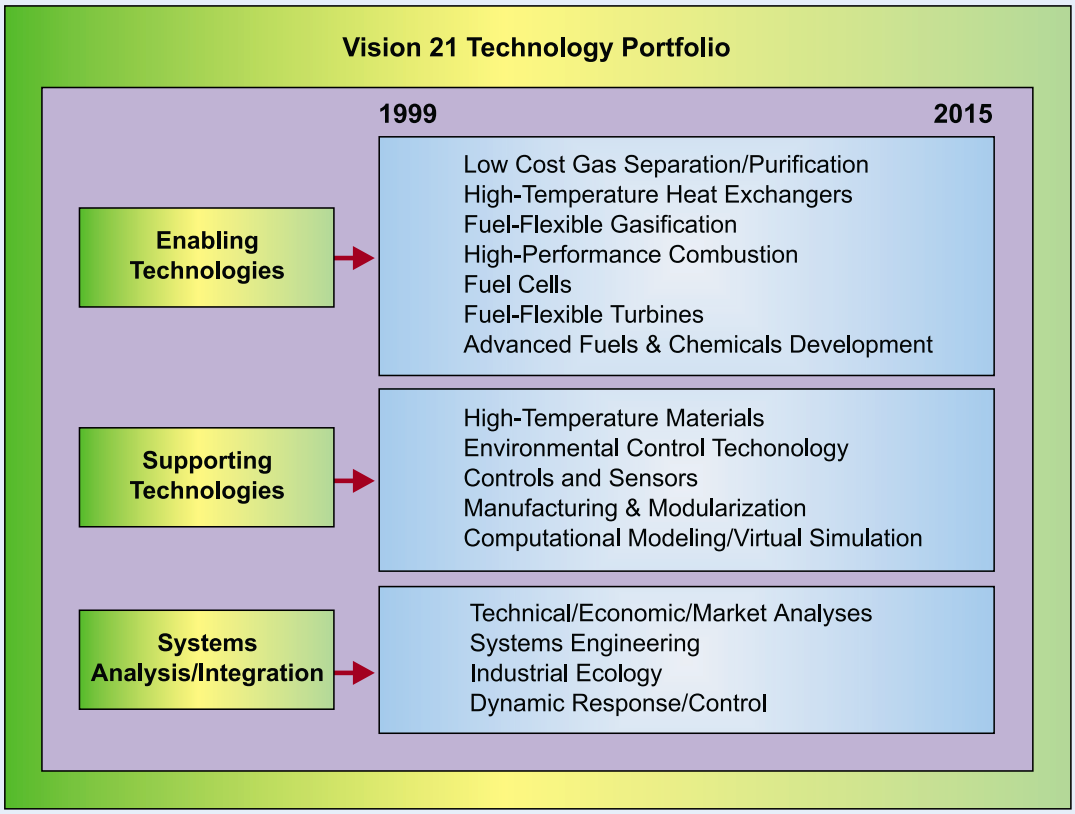
ROADMAP

Process Definition

Market Analysis

Process Evaluation

Economic Analysis



Designs for Components & Subsystems

Designs for Prototype Plants

Designs for Commercial Plants

Virtual Demonstration Capabilities

Drivers

- Continued global economic growth will lead to greatly increased consumption of electricity and fuels.
- The world's total primary energy supply will continue to be dominated by fossil fuels. In 2020, fossil fuels are projected to account for 88 percent of the total primary energy supply.
- Utility deregulation is changing the way the industry operates and invests in new facilities and technology, causing power plant owners in the near term to avoid technical risk and favor low capital cost investments for continued power plant viability and profitability.
- The outlook for future energy supplies and conversion technologies indicates a growing reliance on affordable natural gas as the economic fuel of choice for new electric power generation.
- Restricted availability of gas supplies in many regions and extensive replacements of both coal and nuclear power plants could create many new market opportunities for coal.
- Current technology for producing fuels and chemicals from coal is not only less economical than using natural gas, but also produces at least twice as much carbon dioxide per unit of product as competing technologies based on natural gas.
- Environmental pressures will lead to a global regime of carbon management and widespread, stringent local regulations of air emissions.
- The worldwide demand for low-carbon-emitting and high efficiency technologies and cost-effective carbon capture and disposal techniques is projected to be enormous.
- Technology innovation is the best, and perhaps the only way, to address the coming challenges to the Nation's electric power and fuel supply infrastructure.

Objectives

- Remove environmental barriers to fossil fuel use including smog- and acid-rain-forming pollutants, and particulate and hazardous air pollutants.
- Eliminate solid waste from electricity production by converting it to useful products.
- Reduce carbon dioxide emissions through thermal efficiency improvements and sequestration.
- Keep energy costs affordable.
- Produce useful coproducts from coal including environmentally superior liquid transportation fuels that are cost-competitive with equivalent petroleum products.
- Continue U.S. leadership role in clean energy technology.
- Create partnerships with industry, universities, public and private R&D laboratories, and federal and state agencies to develop cost-effective, marketable Vision 21 components.

Strategies[1]

- Through competitive solicitations, promote public and private sector R&D for the purpose of supporting the continued availability of cost-competitive options for a diverse mix of fossil fuels.
- Through systems analysis, develop Vision 21 system configurations that satisfy program objectives, define performance targets for individual subsystems, and identify supporting technology needs.
- Oversee development of existing enabling technologies in other C&PS programs to ensure technology objectives correspond with Vision 21 objectives and timeline.
- Take the lead in promoting revolutionary R&D in emerging enabling technologies, such as advanced gas separation.
- Guide the Fuels program R&D in pursuing breakthrough technologies for reducing the cost of producing synthesis gas from coal and other high-carbon content fuels.
- Direct R&D in supporting technologies that are necessary for the enabling technologies of Vision 21 to function in commercial applications.
- Enhance CO_2 capture in power systems by promoting oxygen-based (rather than air-based) gasification and combustion that yields a more concentrated, and thus more easily captured and separated, CO_2 effluent stream.
- Develop computer-based capabilities for system simulation, integration, and analysis of Vision 21 technologies at both the component and system levels.
- Promote commercialization of Vision 21 technologies, both domestically and internationally, through continued outreach to educate potential stakeholders and the general public about the credibility, affordability, and productivity that would be provided by Vision 21 plants.

Performance Measures

- Electricity generation efficiencies of 60 percent for coal-based systems and 75 percent for natural gas-based systems. (2015)
- Combined heat and power thermal efficiencies above 85 percent. (2015)
- Achieve 75 percent fuels utilization efficiency when producing fuels such as hydrogen or liquid transportation fuels alone from coal. (2015)
- Near-zero emissions of sulfur and nitrogen oxides, particulate matter, trace elements, and organic compounds. (2015)
- Reduction in CO_2 emissions of 40–50 percent through efficiency improvements; 100 percent reduction with sequestration. (2015)
- Products of Vision 21 plants must be cost-competitive with market clearing prices when commercially deployed. (2015–2020)
- Issue three to five rounds of solicitations for public and private R&D investments in Vision 21 technologies, and promote early commercialization of components, subsystems, and systems. (2001–2015)

[1] A more detailed description of the Vision 21 program strategies including individual program area activities and milestones can be found in the *Vision 21 Program Plan* at www.fe.doe.gov/coal_power/vision21/

Systems Analysis

Systems analysis is a critical part of the Vision 21 program and serves as the "brain" or guiding force for all activities. The key role of systems analysis is to develop Vision 21 system configurations that satisfy the program objectives, to define the performance targets for individual subsystems, and identify supporting technology needs.

Market analysis. These analyses will suggest what features and characteristics of Vision 21 plants are desired by potential purchasers. Adjustments of program emphasis may be made after the market study results are reviewed.

Process definition. Solicitations will be issued in 1999 and again in 2006 to tap into industry's best ideas for defining high-efficiency, high environmental performance Vision 21 systems using natural gas, coal, and other solid fuels such as petroleum coke and municipal and industrial wastes. Contractors will describe their power systems and use computer models to estimate system performance predicated on assumed performance of one or more subsystems or key components that are not yet commercial, but are in development.

Process evaluation. At five-year intervals, a formal assessment will be conducted of current and near-term capabilities for building Vision 21 systems.

Subsystem performance requirements. Following each process evaluation, key process components whose performance must be upgraded to permit significant improvement of overall process efficiency and/or economics will be identified.

Economic analysis. An assessment of capital and operating costs of candidate Vision 21 systems gained during the development phase will be performed after the two reviews of Vision 21 systems and subsystem/component performance requirements.

Subsystem data analysis and model development. Subsystem models will be developed from experimental data and physical principles. State-of-the-art modeling capabilities will be developed.

Enabling Technologies

Enabling technologies are those upon which the subsystems, or modules, that form the building blocks of a Vision 21 plant depend. Some enabling technologies, like gasification and advanced combustion, are already under development, and some are being demonstrated in the CCT demonstration program. Others, such as gas separation, require major improvements to existing technologies. Enabling technologies include:

Gas separation. Examples include membranes that can be used to separate oxygen (O_2) from air, hydrogen from syngas, and CO_2 from combustion products.

High-temperature heat exchangers. Examples include alloy-tube exchangers capable of heating high-temperature steam or air for use in advanced, high-efficiency cycles.

Fuel-flexible gasification. R&D is focused on thermally efficient gasification to allow the use of low-cost feedstocks, such as municipal waste, petcoke, and biomass, with coal.

Gas stream purification. Research is focused on systems capable of operating at high temperatures for removing sulfur compounds and other constituents that may corrode or erode downstream components (e.g., turbines), or poison downstream catalysts.

High-performance combustion systems. Examples include both suspension-fired and fluidized bed, including ultra-low-NO_X combustion and combustion systems that burn fuels in O_2/CO_2 mixtures and produce exhaust streams containing only CO_2 and water.

Fuel-flexible combustion turbines and engine systems. Of particular interest are turbines and engines capable of operating on coal-derived gases or hydrogen; fuel cell/turbine-engine hybrids capable of 70-80% efficiency; advanced combustion turbines, including ceramic turbines and engines; and advanced steam turbines.

Fuel cells. Examples include high-efficiency, low-cost fuel cells; cascaded fuel cell systems capable of operating at multiple temperatures and pressures; fuel cells bottomed by fuel cells; fuel cell/turbine hybrids; new, low-cost fuel cell concepts capable of approaching $100/kilowatt stack costs and, when incorporated into a system, 70-80% system efficiency.

Advanced fuels and chemicals development. R&D is focused on systems and catalysts for fuels and chemicals production as well as hydrogen production and storage.

Supporting Technologies

The ability of a process or power plant to perform to its design capabilities depends in large part on the engineering integrity of its components and support systems. Supporting technologies under Vision 21 are cross-cutting technologies that are necessary for multiple Vision 21 subsystems and components and also important in other, non-Vision 21 applications.

Advanced materials for high-temperature applications. Examples include boiler tubes for high-temperature steam bottoming cycles, and very high-temperature (> 2000 ^{O}F) heat exchangers for use in indirect-fired cycles and other applications, as well as functional materials needed for gas cleanup or separation.

Advanced controls and sensors. Research is focused on advanced controls and sensors for highly integrated Vision 21 plants; new algorithms that use state-of-the-art hardware to assure reliable performance, optimum plant efficiency, and low emissions.

Environmental control technologies. Technologies for low NO_X emissions, control of fine particulate matter, and management of byproducts from Vision 21 plants; improved concepts for CO_2 capture and separation.

Advanced manufacturing and modularization techniques to reduce costs and improve quality.

Advanced computational modeling. The advanced modeling initiative will assist in the design process by providing physically based simulations of Vision 21 plant components. These transient 3-D simulations will realistically account for all the physically relevant phenomenon such as fluid flow, heat transfer, chemistry, and material stress.

Systems Integration

Vision 21 plants will use "smart" systems integration techniques to combine high-performance susbsystems. Systems integration is a principal part of Vision 21 and is necessary to ensure the safe, reliable, and economic operation of Vision 21 plants.

Systems engineering. System configurations that achieve Vision 21 efficiency targets will be examined in the context of identifying factors that can affect compatibility, operability, and system cost. Potential issues include linking gasifiers and combustion turbines, turbines and fuel cells, fuel cells and combustion systems, and gas cleanup devices with other subsystems.

Dynamic response and control. The dynamic response of Vision 21 subsystems to startup and shutdown, changes in load and other operating parameters will be studied, modeled, and validated.

Industrial ecology. Research will focus on recycling, or utilizing in some other manner, *all* process effluents that would otherwise be regarded as waste streams.

Vision 21 Plant Designs

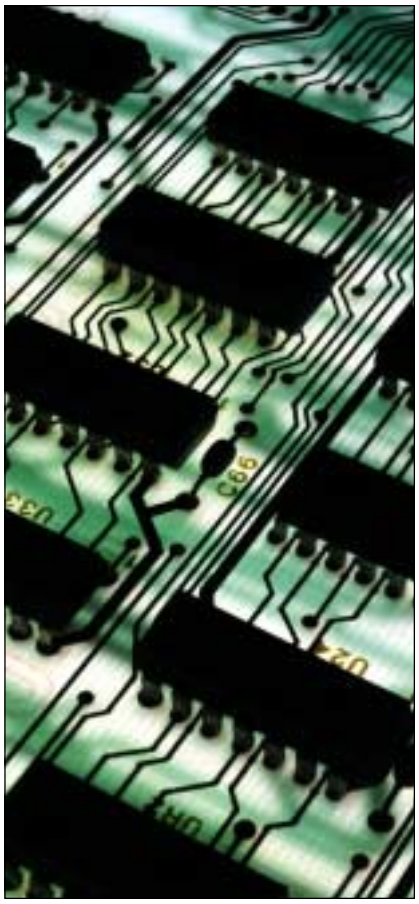
This program area produces the major products of the Vision 21 program and includes the following design elements:

Designs for components and subsystems. Key components (e.g., heat exchangers, pumps, compressors) and subsystems (e.g., turbines, furnaces, gas separators) will be selected and engineering designs will be prepared. Modularity will be emphasized.

Designs for prototype plants. Prototype plants are small, first-of-a-kind, commercial plants intended to show industry that such plants can be built and operated reliably, safely, and economically. Prototype plant designs will be selected based on feedback from market analyses.

Designs for commercial plants. Several configurations for commercial-scale Vision 21 plants will be selected based on the results of market analyses. Sites will be selected and the plant feedstocks, products, configuration, and size will be based on market requirements. Systems integration techniques developed in the Systems Integration program area will be used extensively in the final plant designs.

Virtual demonstration capability. Virtual demonstration of commercial-scale Vision 21 will be conducted in 2015. These demonstrations will illustrate equipment configuration and orientation and include details of plant operation, including dynamic response to changes in load, variations in feedstock properties, changes in component or subsystem operation, and upset conditions.



An example of a Vision 21 plant design is shown above. To learn more about its components, see a video demonstration of this plant at www.fe.doe.gov/coal_power/vision21/index.shtml.

In Partnership with Industry

Industry knows best what its needs are for the short term. But for the long term, industry will need help determining which technologies should be developed and when.

The Vision 21 program addresses anticipated needs in the mid- and long-term, beyond the usual planning horizon of the energy industry.

However, the key to success of the Vision 21 program will be the down-selection of the most promising technologies from many competing technologies, and industry must be closely involved in this process. DOE is providing incentives to share the broad outlines of the Vision 21 plan for the future by creating partnerships with industry, universities, private and public R&D laboratories, and federal and state agencies to plan and implement Vision 21. The National Energy Technlogy Laboratory (NETL) will issue a series of competitive solicitations (the first of which was issued on September 30, 1999), create consortia, and develop Cooperative Research and Development Agreements (CRADAs) and other agreements. Overall program guidance and coordination will be provided by a board of high-level representatives from industry, academia, and government.

Guidance on specific Vision 21 technologies will be provided by technical committees consisting of industry and academic stakeholders. The most recent of these committees met in late August 2000 at the *Vision 21 Roadmapping Workshop* sponsored by NETL. The one-and-a-half day workshop consisted of 101 industry and academic participants organized to revise the Vision 21 technology roadmap, and to make recommendations on critical program priorities.

Because no one knows exactly what future energy plants will look like, the focus of the Vision 21 program is on developing flexible components and subsystems ("modules") that are the building blocks of future Vision 21 plants rather than on the complete plants themselves. The feedstocks, products configuration, environmental controls, and plant size will be site specific and determined by prevailing market and economic conditions.

These activities, the exact timing of which will depend on prevailing economic conditions and market forces, will be left to private industry. DOE's role will be to facilitate the transfer of the Vision 21 data base to industry.

Through the Vision 21 Program, industry-led design and engineering projects will provide the critical building blocks necessary to turn vision into reality. Below is a list of the current industry and academic partners participating in developing Vision 21 technologies:

- FuelCell Energy, Inc.
- Siemens Westinghouse Power Corporation
- Eltron Research, Inc.
- Clean Energy Systems, Inc.
- National Fuel Cell Research Center
- Fluent, Inc.
- Huntington Alloys
- Foster Wheeler Development Corporation
- ITN Energy Systems
- GE Energy and Environmental Research Corp.
- Reaction Engineering International
- CFD Research Corporation
- Princeton University